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Procedia Engineering 15 (2011) 1382 – 1387
Procedia Engineering
www.elsevier.com/locate/procedia

Advanced in Control Engineering and Information Science

The R&D risk for proprietary software producer when open source software appears

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Abstract

By extending Cournot model, this paper investigates how the appearance of open source software (OSS) affects the R&D risk in a market initially monopolized by proprietary software (PS) producer. The software market exhibits network externality. It is found that (i) the R&D risk level of PS producer in the market monopolized by PS isn't higher than in this market emerging OSS; (ii) there exist some R&D cost functions making R&D risk level be lower when PS producer monopolizes the market than when it competes with an OSS producer.

Keywords: risk; R&D; open source software; proprietary software; network externality

1. Introduction

Recent years, open source software has been achieved great success and becomes a powerful rival to proprietary software in many software markets. For examples, in server operating system market, the open source Linux operating system shares about 30%, where Microsoft's Windows, a proprietary software product, holds approximately 50% [1]. Open source software is software whose source code allows software developers to share, identify and correct errors, and redistribute, which is usually available at no charge, and which is often developed by voluntary efforts [2]. Recently, the academic literature has paid close attention to open source problem, in which the research on competition between open source and proprietary software is a hot area. From a technology, user skill and product innovation effort point of view, scholars have investigated the competition between open source and proprietary software (see [3], [4] and [5]). However they haven't analyzed how the emergence of open source software affects the R&D risk of proprietary software producer. In [6], we have considered the R&D risk of proprietary software firm when open source software appears. However, that paper only analyzes a linear R&D risk function and supposes the market doesn't exhibit network externality. By assuming

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doi:10.1016/j.proeng.2011.08.256

software market exhibits network externality and R&D risk function is general, this paper investigates how the appearance of open source software affects the R&D risk of proprietary software producer.

The rest of this paper is organized as follows. Two models are set up and solved in section 2. The optimal R&D risk levels are compared in section 3. The paper is concluded in final part.

2. The basic models

To investigate the influence of open source software to the R&D risk of proprietary software producer, two models are presented in this paper. One model supposes proprietary software producer monopolizes a software market. The other one supposes proprietary software producer competes with open source software. Two models are set up and solved respectively.

2.1. PS monopolizes the market

This part supposes there only exists a proprietary software producer, noted by producer 'p', in a software market. By extending Cournot model, the inverse demand function for PS producer is given by

$$p_p = a_p + \alpha q_p - q_p \,, \tag{1}$$

where a_p and q_p (>0) measure the reservation price and output of proprietary software respectively; αq_p denotes network externality on the demand function, in which α ($\in (0,1)$) represents the intensity of network externality.

To increase software reservation price, proprietary software producer carries on R&D innovation. When the R&D effort for proprietary software producer is λ, it needs to bear investment cost equal to $I(\mu,\sigma)$, which denotes producer's R&D cost function. This paper supposes proprietary software producer is uncertain about the final R&D outcome (λ) when it performs R&D activities, and λ obeys probability distribution $\lambda \sim [\mu,\sigma]$, where $\mu \in [0,\infty)$ and $\sigma \in [\sigma_{\min},\sigma_{\max}]$ denote the expected value and variance of λ respectively (i.e. $E(\lambda)=\mu$ and $V(\lambda)=\sigma$). Moreover, $I(\mu,\sigma)$ is assumed to satisfy $\partial I(\mu,\sigma)/\partial\mu > 0$, $\partial I(\mu,\sigma)/\partial\sigma > 0$, $\partial^2 I(\mu,\sigma)/\partial\sigma^2 \geq 0$ and $\partial I(\mu,\sigma)/\partial\mu\partial\sigma = 0$. After R&D investment, the reservation price for proprietary software is

$$a_p = a_{p_0} + \lambda \,. \tag{2}$$

In (2), a_{p_0} is the software reservation price before PS producer performs R&D activities.

According to (1) and (2), we obtain the profit function for proprietary software producer

$$\pi_p = p_p q_p = (a_{p_0} + \lambda + \alpha q_p - q_p) q_p - I(\mu,\sigma) \,. \tag{3}$$

Note that this paper supposes the marginal cost for proprietary software equals zero.

The timing of PS producer's activities is as follows: it implements R&D innovation in the first stage and decides software quantity in the second stage. We solve the model by backwards induction. The second stage is considered firstly and then the first stage is analyzed.

Stage 2: quantity

By taking the derivative of (3) with respect to q_p, and then setting it equal to zero (i.e. $\partial\pi_p/\partial q_p = a_{p_0} + \lambda - 2(1-\alpha)q_p = 0$), we obtain the optimal quantity of PS producer

$$q_p^* = (a_{p_0} + \lambda)/[2(1-\alpha)] \,. \tag{4}$$

Obviously, q_p^* satisfies the second order condition (i.e. $\partial^2\pi_p/\partial q_p^2 = -2(1-\alpha) < 0$), so it is the unique optimal solution.

Combining (4), (1) and (3), we obtain the profit for proprietary software defined exclusively on R&D effort and risk variable

$$\pi_p = (a_{p_0} + \lambda)^2 / [4(1-\alpha)] - I(\mu,\sigma) . \tag{5}$$

Stage 1: R&D innovation

Proprietary software producer decides R&D risk in this stage. Because PS producer is uncertain about the final R&D outcome when carrying on R&D innovation, it derives optimal decisions by maximizing its expected profit function. Taking the expectation for (5), we obtain

$$E(\pi_p) = (a_{p_0}^2 + 2a_{p_0}\mu + \mu^2 + \sigma) / [4(1-\alpha)] - I(\mu,\sigma) . \tag{6}$$

We only solve the optimal R&D risk and ignore the optimally expected R&D outcome in this paper. Through taking the derivative of (6) with respect to σ, we get

$$\partial E(\pi_p)/\partial\sigma = 1/[4(1-\alpha)] - \partial I(\mu,\sigma)/\partial\sigma . \tag{7}$$

According to (9), there exist four situations for PS producer's optimal R&D risk:

(i) when $\frac{\partial I(\mu,\sigma)}{\partial\sigma} \le \frac{1}{4(1-\alpha)}$ (but $\frac{\partial I(\mu,\sigma)}{\partial\sigma}$ isn't identically equal $\frac{1}{4(1-\alpha)}$) for all $\sigma \in [\sigma_{\min}, \sigma_{\max}]$, $\sigma^* = \sigma_{\max}$;

(ii) when $\frac{\partial I(\mu,\sigma)}{\partial\sigma} \ge \frac{1}{4(1-\alpha)}$ (but $\frac{\partial I(\mu,\sigma)}{\partial\sigma}$ isn't identically equal $\frac{1}{4(1-\alpha)}$) for all $\sigma \in [\sigma_{\min}, \sigma_{\max}]$, $\sigma^* = \sigma_{\min}$;

(iii) when $\frac{\partial I(\mu,\sigma)}{\partial\sigma} \equiv \frac{1}{4(1-\alpha)}$ ($\frac{\partial I(\mu,\sigma)}{\partial\sigma}$ is identically equal $\frac{1}{4(1-\alpha)}$) for all $\sigma \in [\sigma_{\min}, \sigma_{\max}]$, any $\sigma \in [\sigma_{\min}, \sigma_{\max}]$ is an optimal solution. We assume PS producer is conservative and choose the lowest R&D risk, i.e. $\sigma^* = \sigma_{\min}$ in this case;

(iv) when $\frac{\partial I(\mu,\sigma)}{\partial\sigma} = \frac{1}{4(1-\alpha)}$ for some $\sigma \in (\sigma_{\min}, \sigma_{\max})$ (but $\frac{\partial I(\mu,\sigma)}{\partial\sigma}$ isn't identically equal $\frac{1}{4(1-\alpha)}$), there exists a unique optimal solution $\sigma^* \in (\sigma_{\min}, \sigma_{\max})$.

2.2. PS competes with OSS

This part supposes that there exist two software producers in the market. One is a proprietary software producer and the other one is an open source software producer. They are noted by producer 'p' and producer 'o' respectively. The inverse demand functions for proprietary and open source software are respectively given by

$$p_p = a_p + \alpha q_p - q_p - dq_o , \tag{8}$$

$$p_o = a_o + \alpha q_o + \beta q_o - q_o - dq_p - c , \tag{9}$$

where $a_p > 0$, $a_o > 0$, $0 < d < 1$, $0 < \alpha < 1$, $0 < \beta < 1$ and $0 < c < a_o$. In (8) and (9), a_p and a_o measure the reservation prices for proprietary and open source software respectively; d presents the degree of substitution between proprietary and open source software; αq_p and αq_o denote network externality on the demand functions for proprietary and open source software respectively, where q_i ($i = p, o$) is producer i's output (or call network scale); c represents the learning (maintenance or development) cost when users use open source software; β is the contribution degree of each user to the software reservation price when using open source software (or call it user's software development skill parameter).

The timing of producers' activities is as follows: PS producer performs R&D investment in the first stage; PS and OSS producers set software quantity simultaneously in the second stage. Similarly to part 2.1, the model is solved by backwards induction.

Stage 2: quantity

Open source software is usually available at no charge, so this paper assumes $p_o = 0$. Combining with (9), we get $q_o = (a_o - c - dq_p)/(1-\alpha-\beta)$. By substituting q_o into (8) and rearranging, we obtain the price of proprietary software

$$p_p = [(1-\alpha-\beta)(a_{p_0}+\lambda) - d(a_o - c) - ((1-\alpha)(1-\alpha-\beta) - d^2)q_p]/(1-\alpha-\beta) . \tag{10}$$

According to (10) and $p_o = 0$, the profit functions for proprietary and open source software producer are respectively given by

$$\pi_p = p_p q_p - I(\mu,\sigma) = [(1-\alpha-\beta)a_p - d(a_o - c) - ((1-\alpha)(1-\alpha-\beta) - d^2)q_p]q_p/(1-\alpha-\beta) - I(\mu,\sigma) , \tag{11}$$

$$\pi_o = p_o q_o = 0 .$$

(12)

Note that this paper assumes the marginal costs of proprietary and open source software equal zero.

Proprietary software producer pursues profit maximization, so it decides the optimal quantity through (11). Taking the derivative of (11) with respect to q_p, and then setting it equal to zero (i.e. $\partial\pi_p/\partial q_p = 0$), we obtain the optimal quantity of PS producer

$$q_p^* = [(1-\alpha-\beta)(a_{p_0}+\lambda) - d(a_o - c)]/[2((1-\alpha)(1-\alpha-\beta) - d^2)] . \tag{13}$$

This paper supposes the model parameters meet the inequality $q_p^* > 0$. To make sure the optimal solution be unique, q_p^* must meet the second order condition (i.e. $\partial^2\pi_p/\partial q_p^2 < 0$). This condition holds when $[(1-\alpha)(1-\alpha-\beta) - d^2]/(1-\alpha-\beta) > 0$. This paper assumes the model parameters meet the above inequality, so q_p^* is the unique optimal quantity for PS producer.

Combining (13), (10) and (11), PS producer's profit function is given by

$$\pi_p^{'} = \frac{[(1-\alpha-\beta)(a_{p_0}+\lambda) - d(a_o - c)]^2}{4(1-\alpha-\beta)[(1-\alpha)(1-\alpha-\beta) - d^2]} - I(\mu,\sigma) .$$

(14)

Stage 1: R&D innovation

The expectation for (14) is given by

$$E(\pi_p^{'}) = \frac{(1-\alpha-\beta)^2(a_{p_0}^2 + 2a_{p_0}\mu + \mu^2 + \sigma) - 2d(1-\alpha-\beta)(a_o - c)(a_{p_0}+\mu) + d^2(a_o - c)^2}{4(1-\alpha-\beta)[(1-\alpha)(1-\alpha-\beta) - d^2]} - I(\mu,\sigma) .$$

(15)

Taking the derivative of (15) with respect to σ, we derive

$$\frac{\partial E(\pi_p^{'})}{\partial\sigma} = \frac{1}{4[(1-\alpha) - d^2/(1-\alpha-\beta)]} - \frac{\partial I(\mu,\sigma)}{\partial\sigma} .$$

(16)

According to (16), there exist four situations for PS producer's optimal R&D risk:

(i) when $\frac{\partial I(\mu,\sigma)}{\partial\sigma} \le \frac{1}{4[(1-\alpha) - d^2/(1-\alpha-\beta)]}$ (but $\frac{\partial I(\mu,\sigma)}{\partial\sigma}$ isn't identically equal $\frac{1}{4[(1-\alpha) - d^2/(1-\alpha-\beta)]}$) for all $\sigma \in [\sigma_{\min}, \sigma_{\max}]$, $\sigma^* = \sigma_{\max}$;

(ii) when $\frac{\partial I(\mu,\sigma)}{\partial\sigma} \ge \frac{1}{4[(1-\alpha) - d^2/(1-\alpha-\beta)]}$ (but $\frac{\partial I(\mu,\sigma)}{\partial\sigma}$ isn't identically equal $\frac{1}{4[(1-\alpha) - d^2/(1-\alpha-\beta)]}$) for all $\sigma \in [\sigma_{\min}, \sigma_{\max}]$, $\sigma^* = \sigma_{\min}$;

(iii) when $\frac{\partial I(\mu,\sigma)}{\partial\sigma} \equiv \frac{1}{4[(1-\alpha)-d^2/(1-\alpha-\beta)]}$ ($\frac{\partial I(\mu,\sigma)}{\partial\sigma}$ is identically equal $\frac{1}{4[(1-\alpha)-d^2/(1-\alpha-\beta)]}$) for all $\sigma \in [\sigma_{\min}, \sigma_{\max}]$, any $\sigma \in [\sigma_{\min}, \sigma_{\max}]$ is an optimal solution. We assume PS producer is conservative and choose the lowest R&D risk, i.e. $\sigma'^{*} = \sigma_{\min}$ in this case;

(iv) when $\frac{\partial I(\mu,\sigma)}{\partial\sigma} = \frac{1}{4[(1-\alpha)-d^2/(1-\alpha-\beta)]}$ for some $\sigma \in (\sigma_{\min}, \sigma_{\max})$ (but $\frac{\partial I(\mu,\sigma)}{\partial\sigma}$ isn't identically equal $\frac{1}{4[(1-\alpha)-d^2/(1-\alpha-\beta)]}$), there exists a unique optimal solution $\sigma'^{*} \in (\sigma_{\min}, \sigma_{\max})$.

3. Comparison

In this part, the optimal R&D risks of two models obtained in part 2 are compared. For comparative analysis, the intensities of network externality in two models are assumed to be equal. The following conclusions can be proven.

Proposition 1: (i) for a given $I(\mu,\sigma)$, there is $\sigma'^{*} \geq \sigma^{*}$; (ii) there exists $I(\mu,\sigma)$ making $\sigma'^{*} > \sigma^{*}$.

The first part of proposition 1 demonstrates that the R&D risk level of PS producer isn't higher in a monopoly market than in a duopoly market facing an OSS. The second part indicates that there exist some R&D cost functions making R&D risk level for PS producer be lower when it monopolizes the market than when it competes with OSS producer.

Proposition 2: when both $\sigma^{*} \in (\sigma_{\min}, \sigma_{\max})$ and $\sigma'^{*} \in (\sigma_{\min}, \sigma_{\max})$ for a given $I(\mu,\sigma)$, there are (i) $\sigma'^{*} > \sigma^{*}$; (ii) $\sigma'^{*} - \sigma^{*}$ increases with α , β and d .

The proposition 2 demonstrates that, if there exist inner solutions for a given R&D cost function in both models, the optimal R&D risk level when PS producer monopolizes the market is lower than when it competes with OSS producer, and the difference increases with OSS user's software development capacity, the network externality intensity and substitution degree between PS and OSS.

4. Conclusions

We analyze how the appearance of open source software affects the R&D risk of proprietary software producer in this paper. Proprietary software producer pursues profit maximization and open source software is free for users. Moreover, we assume the software market exhibits network externality. The following conclusions are obtained: (i) the R&D risk level for PS producer isn't higher (resp. there exist R&D cost functions making the R&D risk level for PS producer be lower) when the software market is monopolized by PS than when it also exists OSS; (ii) if there exist inner solutions for a given R&D cost function, the optimal R&D risk level when PS producer monopolizes the market is lower than when it competes with OSS producer, and the R&D level difference increases with the OSS user's software development skill, the network externality intensity and substitution degree between PS and OSS.

References

[1] Netcraft, September 2001 web server survey. Available from: http://survey.netcraft.com/Survey/index-200109.html.

[2] O'Reilly T. Lessons from open-source software development. *Communications of the ACM* 1999; **42**:33-37.

[3] Dalle J, Jullien N. Open-source vs. proprietary software. Working paper; 2002.

[4] Lin LH. Impact of user skills and network effects on the competition between open source and proprietary software. *Electronic Commerce Research and Applications* 2008; **7**:1-4.

[5] Xing MQ. Proprietary software's R&D decisions when open source software appears in a software industry. The International Conference on E-Product, E-Service and E-Entertainment, Jiaozuo, China; 2010.

[6] Xing MQ. Can open source software affect the R&D risk choices of proprietary software producer. The 3rd IEEE International Conference on Information Management and Engineering, Zhengzhou, China; 2011.